Describing auger operation by means of dimension analysis

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Design and research of auger conveyors by dimensional analysis has a lot of advantage. This powerful tool provides an orderly method for combining the many variables influence on auger conveyor performance which avoid the purely theoretical approaches. According to the principle auger conveyors can be considered similar that characterized by same independent similarity (dimensionless) variables. The performance (capacity, energy requirement etc.) of similar augers can be satisfactory predicted before they leave the drawing boards if the variables groups are known. Other advantage of dimensional analysis are that the number of variables decrease due to they are grouped therefore the results of tests or investigations become clearly arranged.

The dimension analysis is not a new approach to the research on the design and operation of auger. Publications concerning the application appeared already in the sixties abroad. According to the experiences the moment requirement and the transport rate can be calculated from empirical equations containing dimensionless numbers set up using dimension analysis [3]. Unfortunately the method did not spread in the home research and design in spite of its several advantages. This effective method makes possible to take into account such characteristics an variables in the description of transport augers which can not be examined in mere theoretical approaches [2].

The analysis of dimensions is based on the conclusion of the similarity theory that the solution to the mathematical model of a phenomenon can be given as function relationships of dimensionless numbers called also dependent and independent invariant numbers. All the phenomena which are described by the same dimension less equation make a class of the similar phenomena. Among them the group of similar phenomena is formed by those phenomena for which values of the independent invariant numbers in the unicity conditions i.e. of similarity criteria are identical [4].

An advantage of using dimension analysis is that the operational parameters (expected output rate, power need, etc.) of transport augers belonging to the same group can be estimated even in the design period having the measuring data for the group.

Another advantage rises up at the investigation of the apparatuses. The measuring results in the form of charts, diagrams or functions for more than 2 or 3 variables become not clear-cut. With the help of dimension analysis one can have a picture of the phenomena in the form of relationship of much less dimension less numbers than the actual number of variables.

Dimensionless numbers of the transport auger

The first step of the dimension analysis is the determination of the dimensionless numbers (i.e. dependent and independent similarity invariant numbers) of the phenomenon examined which is a routine process if the variables are known. The complete success of the analysis depends on the correct selection of the variables describing the phenomenon. Unfortunately there is no rule of judging which variables are important or negligible, one can recline only on the anticipation and experience. That is why the selection of the variables needs thorough analysis and attention.

In case of transport augers the output rate and the moment requirement are considered as dependent variables. The reachable transport capacity - as it is know - is a function of the geometry dimensions and the rotational velocity, so that one should decide in the initial stage of the designing how much output rate should be produced. At the same time the output rate will determine the application possibility, too. For example, if a transport auger are to be fitted in a transport aggregate, that is selected on the basis of transport capacity expressed by the value of the transported volume or mass rate. Similarly, the driving moment requirement is also an important characteristic. During the designing the drive and the motor are selected on the basis of driving moment need and the revolution speed. The operator is interested in values for the assurance of the electric power needed by the driving.

The parameters influencing the operation of the auger can be put into three groups, such as geometric (design) variables, operational variables and material characteristics. The variables necessary to produce the dimension analysis or dimension matrix are summarized in *Table 1.*

Table 1

Variable	Notation	Unit	Dimension
Geometry variables			
angle of transport	δ	°	-
diameter of auger wing	D	m	L
length of inlet port	Z	m	L
length of auger wing	L	m	L
diameter of auger shaft	d	m	L
inside diameter of auger house	D_{cs}	m	L
auger pitch	s	m	L
Operational variables			
revolution	n	1/s	T^{-1}
gravitational acceleration	g	m/s^2	LT^{2}
torque requirement	M	Nm	ML^2T^{-2}
volumetric output rate	Q	m^3/s	L^3T^{-1}
Material characteristics			
moisture content	W	%	-
bulk density	ρ	kg/m^3	ML^{-3}

Table 2

		ln(L)	ln(M)	ln(T)
		z_1	z_2	z_3
ln(D)	y_1	1	0	0
ln(ρ)	y_2	-3	1	0
ln(g)	y_3	1	0	-2
ln(δ)	y_4	0	0	0
ln(Z)	y_5	1	0	0
ln(L)	y_6	1	0	0
ln(d)	y_7	1	0	0
ln(D_{cs})	y_8	1	0	0
ln(s)	y_9	1	0	0
ln(n)	y_{10}	0	0	-1
ln(Q)	y_{11}	3	0	-1
ln(W)	y_{12}	0	0	0
ln(M)	y_{13}	2	1	-2

The dimensions of the variables can be written as the multiplication of the powers of the dimensions of the basic units (in a given system of units). The SI system dimensions of the characteristic variables are given in the last column of *Table 1.* The basic units of SI are the length (L), mass (M) and the time (T). The dimension matrix constructed from them is shown in *Table* 2, where the variables are arranged such way which helps the determination of dimensionless numbers because the first three rows makes a rectangular partition of non-singular matrix. In addition for simplicity, the logarithm of the dimensions of variables and the logarithm of the dimensions of the basic units are denoted by y_i (i=1,2, ... , 13), and z_j (j=1,2,3), respectively.

There are several type method of determining dimensionless number. One of the most effective among them is the so called base factor method [1]. Its essence is the decomposition of the dimension matrix into base factors i.e. the multiplication of two matrices the first the second of which contains linearly independent columns and rows, respectively. Then the base elements of physical quantities can be determined from the base factors. The decomposition to factors usually can be avoid if one manages to write the matrix such way that the first rectangular partition is non-singular, lower triangular matrix. In the case the, procedure is as follows.

From the first three equations:

$$z_1 = y_1,$$
$$z_2 = y_2 + 3z_1 = 3y_1 + y_2,$$
$$z_3 = \frac{1}{2}(z_1 - y_3) = \frac{y_1}{2} - \frac{y_3}{2}.$$

Substituting z_1, z_2 and z_3 values in the further equations

$$y_1 - y_5 = 0,$$
$$y_1 - y_6 = 0,$$
$$y_1 - y_7 = 0,$$
$$y_1 - y_8 = 0,$$
$$y_1 - y_9 = 0,$$
$$y_1 - y_3 + 2y_{10} = 0,$$
$$5y_1 + y_3 - 2y_{11} = 0,$$
$$4y_1 + y_2 + y_3 - y_{13} = 0.$$

And returned to the original notations

$$\ln(D) - \ln(Z) = 0,$$
$$\ln(D) - \ln(L) = 0,$$
$$\ln(D) - \ln(d) = 0,$$
$$\ln(D) - \ln(D_{cs}) = 0,$$
$$\ln(D) - \ln(s) = 0,$$
$$\ln(D) - \ln(g) + 2\ln(n) = 0,$$
$$5\ln(D) + \ln(g) - 2\ln(Q) = 0,$$
$$4\ln(D) + \ln(\rho) + \ln(g) - \ln(M) = 0.$$

The invariant numbers formed from the above equations are

$$P_1 = \frac{M}{D^4\rho g},\ P_2 = \frac{Q^2}{D^5 g},\ P_3 = \frac{Dn^2}{g},\ P_4 = \frac{s}{D},\ P_5 = \frac{D_{cs}}{D},\ P_6 = \frac{d}{D},\ P_7 = \frac{L}{D},\ P_8 = \frac{Z}{D},$$

which are completed by adding $P_9 = \delta$ and $P_{10} = W$.

The application of the method

Let us consider *Fig 1* and *2* to demonstrate the applicability of the method which represent the partial results of the experiments on autumn barley with auger of parameters given in *Table* 3. The parameters are not detailed here.

Table 3

Description of variable	Notation	Unit	Adjusted value
angle of transport	δ	°	10, 30, 50, 70
diameter of auger wing	D	m	0,130
length of inlet port	Z	m	0,295
length of auger wing	L	m	2,0
diameter of auger shaft	d	m	0,027
inside diameter of auger house	D_{cs}	m	0,152
auger pitch	s	m	0,133
revolution	n	1/min	300-1000
moisture content	W	%	9-12

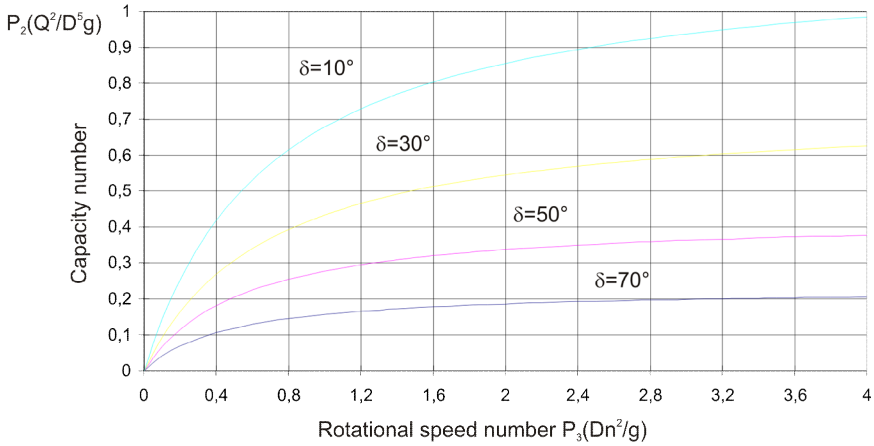

Fig 1 Capacity number as a function of rotation speed number

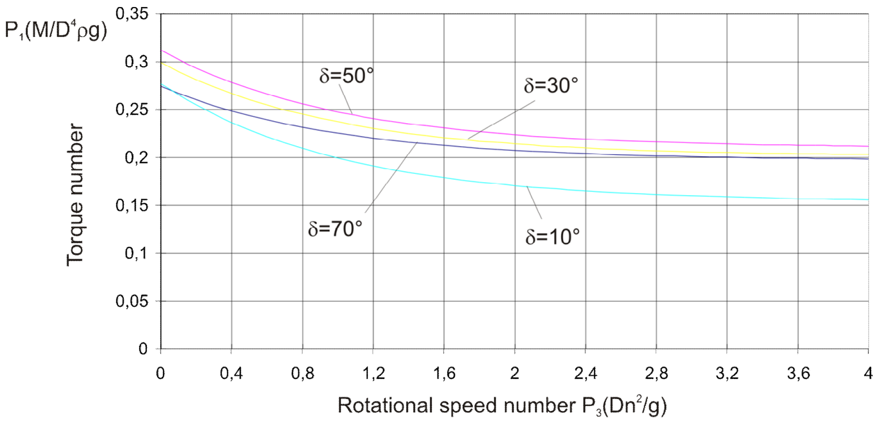

Fig 2 Torque number as a function of rotation speed number

In the *Fig 1* one can recognize the variation of the so called **capacity number** (P_2) as function of **rotational speed number** (P_3) and the angle of transport (P_9) all the other invariant numbers are constant. In the *Fig 2* the **torque number** measured simultaneously with the capacity number is demonstrated. One can easily see that the figures contain information not only for the transport capacity and moment need of the D=130 mm diameter auger applied in the experiment but they describe the variation of all augers which have identical independent invariant numbers. It means that it is enough to manufacture and measure only one single experimental equipment to estimate the expectable transport capacity and driving moment need of different size transport augers.

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Publikálva:
Hungarian Agricultural Engineering N° 10/1997 15-16 p.